Industrial Articles Presented in International Conference on Process Engineering and Advanced Materials (ICPEAM2020), 13-15 July 2021

OPTIMISING FOR VIABILITY – REVAMPING VACUUM DISTILLATION UNIT IN A BROWNFIELD PROJECT

Saiful Anuar Mohd Mokhtar*, Marina Mosir

Petroliam Nasional Berhad (PETRONAS), Kuala Lumpur, Malaysia

*Email :saifulmokhtar@petronas.com

ABSTRACT

Revamping an existing column in an operating plant for higher throughput is always challenging, especially when operating at its rated capacity. This is particularly true for a Vacuum Distillation Unit (VDU) column which involves multiple product and pump-around streams and associated auxiliary units like a steam ejector system. Optimising the design and operation of the column, hence, is inevitable to ensure the viability of a brownfield project as it avoids major modifications required to the column and its associated auxiliary systems. This paper discusses how optimisation was done on an existing VDU column design and operation in an oil refinery, avoiding major modifications of the associated ejector, steam, cooling water, sour water systems, and heat exchanger network, allowing a brownfield project to stay commercially viable.

INTRODUCTION

A case study of an existing VDU column at an existing refinery in Malaysia is deliberated in this paper. The VDU column was designed to operate at 9 mmHg operating pressure with a throughput capacity of 3.5 kilo barrel per day (kbpd) of Low Sulfur Waxy Residue (LSWR) from an upstream Crude Distillation Unit (CDU). As part of the refinery business strategy, the VDU column was contemplated debottlenecked to allow additional throughput of LSWR, which is lighter than the existing throughput at 23 kbpd unit. The lighter and higher LSWR throughput led to higher non-condensable, condensable vapour flows at the top of the column, increasing the internal column loading massively, producing higher column operating pressure, and causing additional burden to the overhead steam ejector system. Significant modifications to the column shell diameters, steam ejectors, and condensers were expected, and the equipment's replacement will require massive structural modification within an existing congested operating plant.

On top of that, with the larger steam ejectors and condensers, major modifications to the associated steam generation system, cooling water system, and sour water treating unit was expected. It was estimated that the total cost of modifications required was in the order of USD25 million, which may render the project uneconomical. Replacing the VDU column itself is not an option given the sheer complexity of the construction works required in the existing operating plant, requiring extended downtime of the refinery. The economic loss associated with the prolonged downtime outweighs the benefit of debottlenecking the column itself.

METHODOLOGY

One way to allow the project to be economically viable is by optimising column operating conditions, column internal design efficiencies, and exhausting all available heat duties within the pump-around and heat integration network to reduce the impact on the existing ejector system and minimising the modifications to VDU unit. This was performed using industrially acceptable process simulators and in-house sizing software for column internals.

Optimising the column operating conditions includes increasing column bed efficiencies, adjusting the operating pressure, redistributing heat duties in the heat exchanger network, optimising pump-around flow, adjusting the column temperature profile and the column inlet temperature. This, in return, translates into changes of both mass and heat transfer profile within the column which resulted in the reduction of internal column liquid and vapour traffic and reduced the total load at the top of the column to the overhead steam ejector system.

Debottlenecking a VDU Column

Understanding how a VDU column works and the influence of the auxiliary systems on the VDU column operation is key in optimising both the design and operation of the column itself. The VDU column understudy was a typical 5 packed bed, 1 flashing section, and 1 stripping section column design, operated under vacuum conditions at 9 mmHg and was designed to fractionate heavy LSWR into product streams such as Light Vacuum Gas Oil (LVGO), Medium Vacuum Gas Oil (MVGO), Heavy Vacuum Gas Oil (HVGO) and Vacuum Residue (VR). See Figure 1 for the schematic of the VDU under study.

A 2-phase feed enters the VDU column flashing section via an upstream fired heater. Lighter vapor components will raise the column to the wash, Bottom Pump-around (BPA), Middle Pump-around (MPA), Fractionation, and Top Pump-around (TPA) sections to be further distillate to product streams through both the heat recovery pump-around beds and product purification beds. The heavier liquid components will go down the column bottom through the stripping section to ensure the lighter portion can still be recovered before coming out of the VDU column as the Vacuum Residue (VR) product stream.

The VDU debottlenecking project will introduce lighter LSWR at an increased capacity from 3.5 kbpd to 23 kpbd into the VDU column. Due to the higher throughput, to allow for adequate separation within the column, a new fired heater was added upstream of the VDU column to provide additional 20 MW heat duty to the VDU column. Hence, to meet the debottlenecking objectives, the column receives additional mass throughput and receives additional heat load to the column heat balance.

Through detailed tray-to-tray simulation and hydraulic sizing calculation performed at each of the column internals, it was observed that introducing additional mass throughput and heat load to the column causes the following:

1. Substantially massive vapour traffic rises the column from the flashing section to the TPA section.
2. Higher pump-around duty requirement for all pump-around sections due to higher vapor traffic inside the column. This is to balance out the additional heat introduced by the new fired heater.
3. Due to higher vapor traffic in the column, lighter components slipped down to the VR section and compromises the initial boiling point (IBP) specification.
4. Additional column pump-down requirement at Fractionation and Wash Oil sections due to increasing in liquid load.
5. Higher pressure drop across the column due to higher hold-ups caused by higher liquid and vapour traffic.

The above changes to the column operating conditions would translate into major modifications to the VDU column and its auxiliary systems if no optimisation were performed on the column's internal design and operation.

VDU Column Modification without Optimisation

The conventional way of debottlenecking a VDU column will involve total revamp of the column itself, which could include total replacement of the column internals to higher performance internals, increasing the column inlet and outlet nozzles, allowing larger column diameter and to the extreme of total replacement of the VDU column itself. To manage the additional heat load introduced into the VDU column heat balance, additional external cooling or heat sinks need to be introduced either by introducing additional heat exchangers in the heat exchanger network or provision of new water or air coolers.

In addition to the above, a higher vapour load that exits the top of the column, consisting of both condensable and non-condensable hydrocarbon components, could result in a massive multi-stage ejector modification

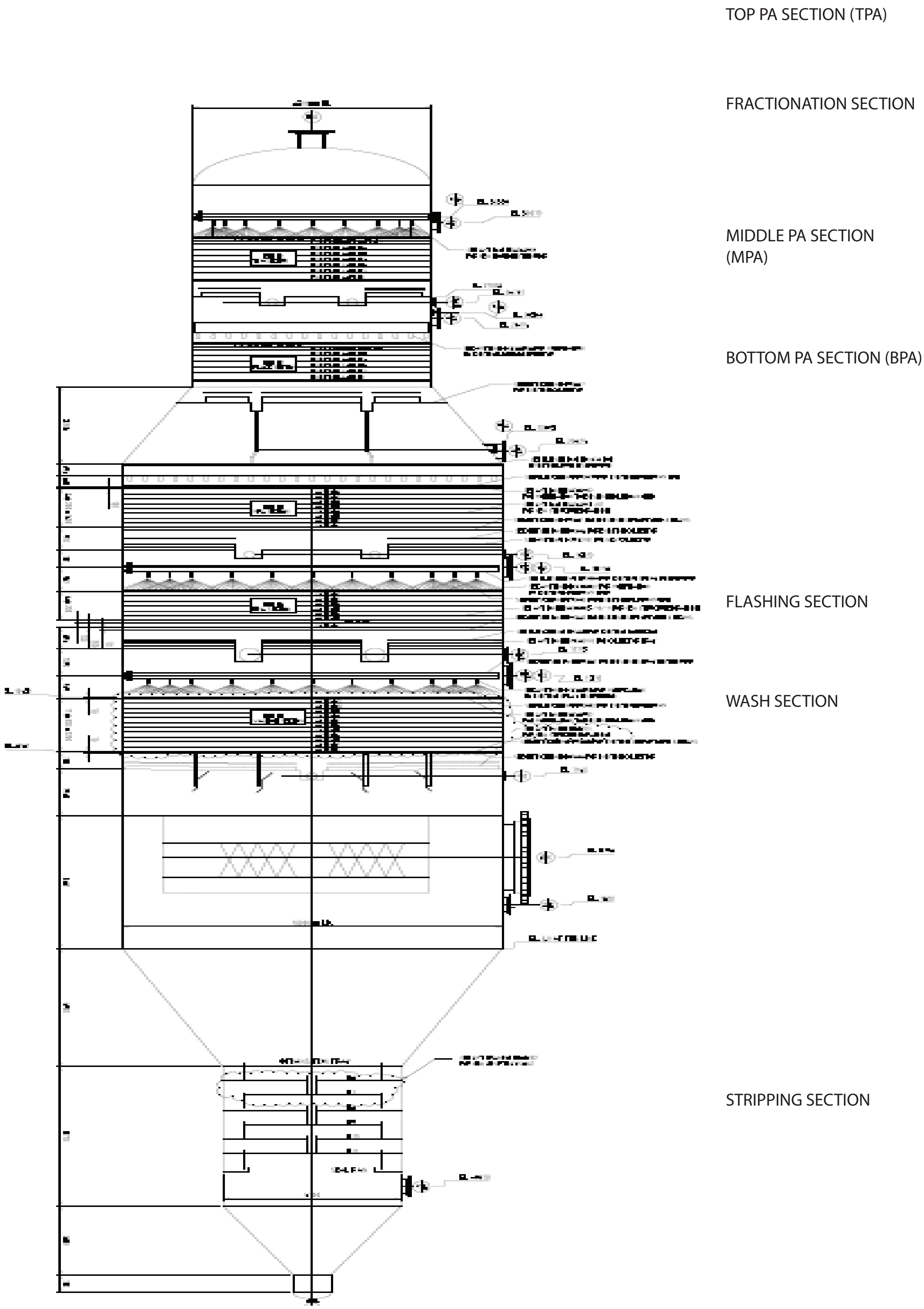

Figure 1 Vacuum Distillation Column

requirement. Significant modifications to the associated steam generation system, cooling water system, and sour water treating unit was expected to support the ejector modification. Section 3 summarises the modification required should optimisation was not opted.

VDU Column Modification with Optimisation

In preventing major modifications to the VDU column, the column design and operation were optimised before the modification scope was identified. The VDU column operating parameters and each section within the VDU column were examined in detail. Iterative simulations were performed to ensure each bed within the VDU column can be fully optimised. Below optimisation approach was applied to minimise the scope of the VDU column modifications:

1. Fired Heater Coil Outlet Temperature (COT) into the VDU column was reduced from the design operating temperature to the lowest operating temperature. The column is still able to allow good separation to occur within the column. This optimises the heat balance within the VDU column and the capital investment required to handle the additional heat within the heat exchanger network.
2. Column top vacuum operating pressure was increased from the design operating pressure to the maximum operating pressure. The column is still able to accommodate to good separation to occur within the column. This reduces the amount of condensable and non-condensable at the vapour outlet of the VDU column to the ejector system, avoiding major modifications to the ejector system and associated steam, cooling water, and sour water treating units.
3. For all heat recovery pump-around beds within the VDU column, i.e., TPA, MPA, and BPA, a high-efficiency packing type with the additional surface area was selected. This packing selected does not sacrifice the void fraction, i.e., the capability to withstand the higher load.
4. The heat recovery through the heat exchanger network was optimised to achieve maximum heat integration within the VDU unit and minimise capital investment for modification of existing heat exchangers except for additional water or air coolers for final heat rejection. This is achievable through a higher efficiency bed at both TPA and MPA sections, allowing better heat recovery at lower pump-around flow, reducing internal column vapour and liquid traffic, and improving heat recovery in the highly integrated heat exchanger network.
5. For all fractionation packing beds within the VDU unit, i.e., fractionation section and wash section, the latest development in the technology of the hybrid packed bed was chosen to provide a better performance, i.e., higher void fraction sacrificing the efficiency, i.e., surface area. The hydraulic limitation was reduced without increasing column diameter while separation and product quality were met using the high-efficiency packed bed. This avoids any modification to the VDU column shell itself.

With the optimisation approaches above, it was observed that the VDU column total internal vapour and liquid traffic was significantly reduced throughout the column while maintaining the separation and quality of the product. The optimisation has also resulted in smaller vapour condensable and non-condensable flows at the top of the column. These avoid major modifications to the VDU column, its auxiliary systems, and the heat exchanger network, significantly reducing capital investment of the brownfield project. Section 3 summarises the modification required with optimisation being executed.

RESULTS AND DISCUSSION

The modifications required for the VDU column with and without the optimisation are listed below in Table 1.

The optimisation of the VDU column operating conditions and internal design avoids replacement of the 1st Stage Ejector (most extensive ejector system) and associated steel structure for the ejector system and requirement for a new Cooling Water Package and associated interconnected piping, a new Steam Generation Package and associated interconnected piping, a new Sour Water Treating Unit, and additional heat exchangers, cooling water or air coolers in the heat exchanger network. It is estimated that the total cost

Table 1 VDU Revamp Scope with and without optimisation

	Without Optimisation	With Optimisation
Base Scope	VDU Column Shell and Nozzle Modification • VDU Column shell diameter increase (+15% diameter) • VDU Column height increase (+10% high). • Increase TPA return nozzle size and change spray distributor (+25% increase in size).	VDU Column Shell and Nozzle Modification • Increase TPA return nozzle size and change spray distributor (+25% increase in size).
	Packing Beds and Internal Replacement • Replacement of the TPA, MPA, and BPA section to the high capacity type of packed bed without reducing the efficiency. • Replacement of the TPA, MPA, and BPA section to the high capacity type of packed bed without reducing the efficiency.	Packing Beds and Internal Replacement • Replacement of the TPA, MPA, and BPA section to the high capacity type of packed bed without reducing the efficiency. • Replacement of the TPA, MPA, and BPA section to the high capacity type of packed bed without reducing the efficiency. The latest development in the technology of hybrid packed beds was chosen.
	Replacement of Top Pumparound (TPA) Air coolers (+25% duty)	Replacement of Top Pumparound (TPA) Air coolers (+25% duty)
	Replacement of LVGO Pumps (+150% capacity)	Replacement of LVGO Pumps (+40% capacity)
	Replacement of Middle Pumparound (MPA)/ MVGO Pumps (+93% capacity)	Replacement of Middle Pumparound (MPA)/MVGO Pumps (+95% capacity)
	Replacement of Extra Heavy Vacuum Gas Oil (XHVGO) Recycle Pumps (+20% head rise)	Replacement of Extra Heavy Vacuum Gas Oil (XHVGO) Recycle Pumps (+20% head rise)
	Replacement of Vacuum Residue Pump (+35% capacity)	Replacement of Vacuum Residue Pump (+35% capacity and +30% head rise)
Additional Scope	Replacement of 1st Stage Ejector (most extensive ejector system) (an increase from 15m length to 42 m length) and associated steel structure for the new ejector system.	Replacement of Third Stage Ejector (smallest ejector system) (an increase from 1m length to 1.6 m length).
	New Cooling Water Package and associated interconnected piping (+1670 m^3/hr ton/hr capacity)	Replacement of VR/LSWR Cooler (+7% duty)
	New Steam Generation Package and associated interconnected piping (+59.5 ton/hour capacity)	
	New Sour Water Treating Unit (+59.5 ton/hr capacity)	

avoidance is USD25 million due to the optimisation work. This allows the project to stay economically viable.

The project has recently undergone a performance test run (PTR) and proven to meet the desired performance guarantee.

CONCLUSION

In conclusion, optimisation of a column's operating conditions and design is critical, particularly for a complex column like a VDU column, primarily when the column is already operating at its rated capacity in a brownfield project. A case study of a VDU column in an oil refinery in Malaysia indicates that massive modifications are required if optimisation is not done on the column operating conditions which add unnecessary capital expenditures and may render the project economically unviable. However, optimisation of the operating conditions should be done cautiously with adequate verification work being performed. This ensures that the column performance is not jeopardised and the project can still meet the performance guarantee.

REFERENCES

AspenTech, "Advanced Column" in *Advanced Process Modeling Using Hysys*, Massachusetts, USA, Aspen Technology, Inc, Chapter 3, pp. 3-1 – 3-18, 2004.

H. Z. Kister, *Distillation Design*, New York, USA: McGraw-Hill Book Company, 1992.

J. M. Douglas, "Complex Distillation Columns," in *Conceptual Design of Chemical Processes*, International Edition. Massachusetts, USA: MacGraw-Hill Book Company, 1998.

L. Hugo, "Atmospheric Crude Tower" in *Hysys.Process Manual*, Calgary, Canada: Hyprotech Limited, Chapter R1, pp. R1-1 – R1-14, 1998.